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Changes in Aerospace Electronics and the Impact on Life Cycle Considerations

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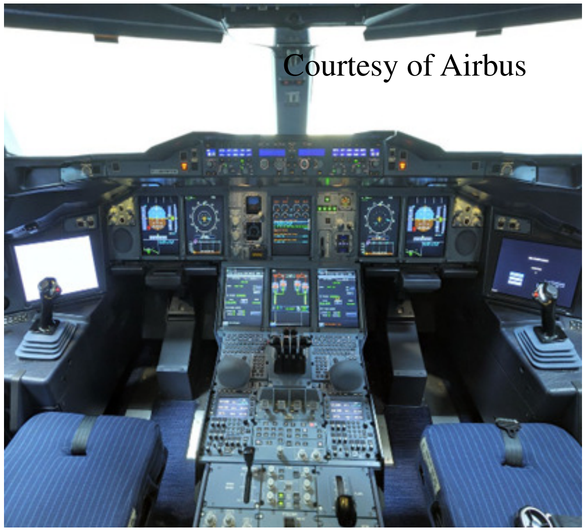
Aerospace Electronics (Avionics)

- Electronics are key to aerospace systems, ranging from flight controls, to engine control and to system level communications.
- Avionics account for **more than 30%** of the total cost of the aircraft.
- Advanced avionics systems automatically perform many tasks that pilots and navigators previously did by hand
  - Area navigation (RNAV) or flight management system (FMS) unit accepts a list of points that define a flight route, and automatically performs most of the course, distance, time, and fuel calculations
  - Autopilot is capable of automatically steering the aircraft along the route

Source: NASA



Courtesy of Airbus

Transition from Military to Commercial of the Shelf Electronics (COTS)

- Defense funded research and development once drove commercial technology, but now **commercial technologies lead the DOD** in many key areas.
- Providing specialized **low volume** parts for aerospace and military are **no longer profitable** for electronics manufacturers
- Design and manufacturing of electronics are **increasingly global**.
- **Shrinking budgets and affordability** of leading edge technologies in COTS components, modules and assemblies.
- Commercial suppliers are designing electronics that can be used in **multiple applications**, satisfy size, weight and power requirements and provide more multi-function applications.
- Rather than designing new electronics from the ground up (a costly and time-consuming procedure), some products make use of existing technologies and **hardens** them for expanded use cases.

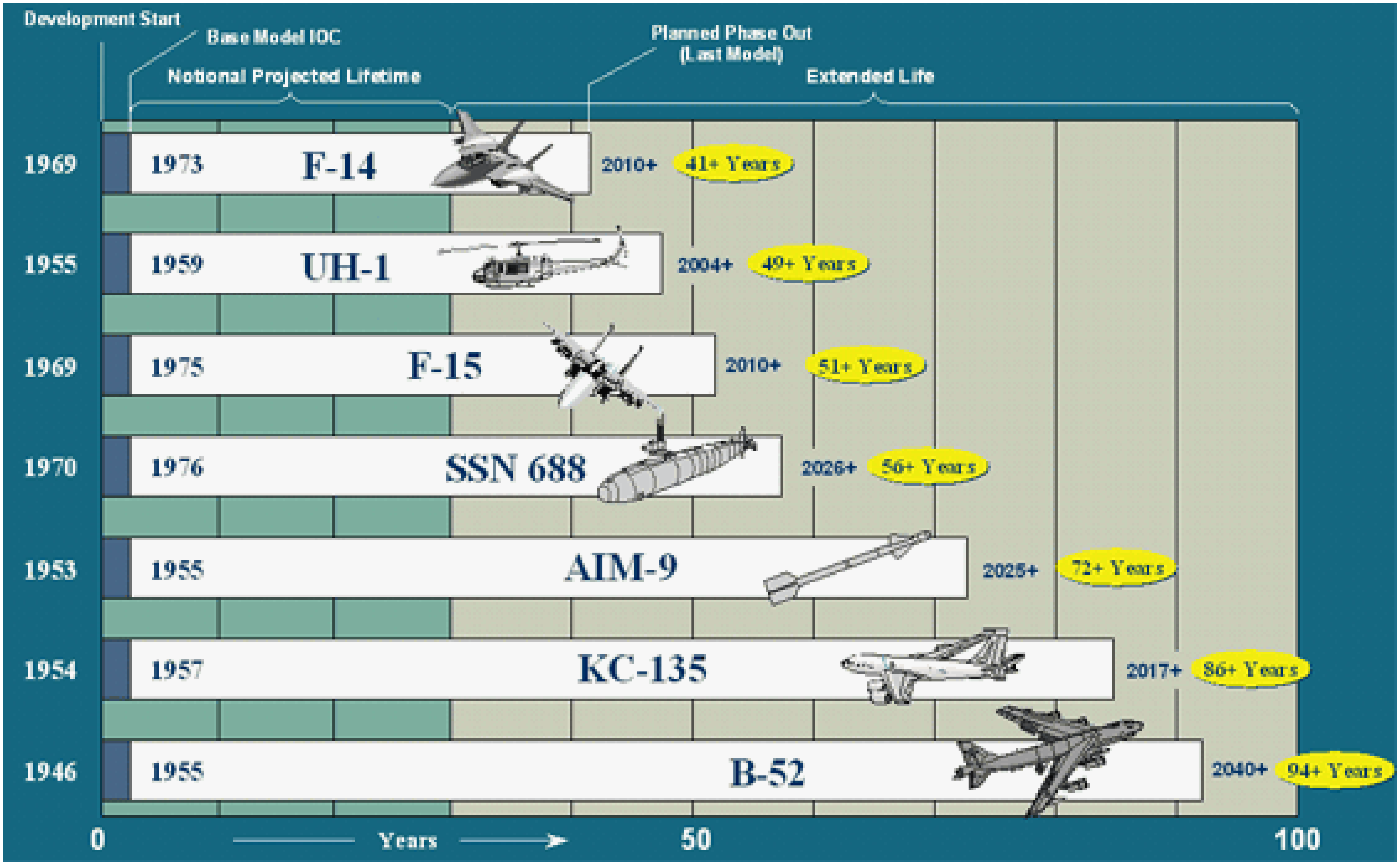
Space - COTS

- With the retirement of NASA's space shuttles, NASA is trying to encourage private space companies to build space crafts.
  - Boeing (CST-100 capsule)
  - Space X (Dragon)
  - Sierra Nevada Corp (Dream Chaser)
- These private companies are sourcing their electronics from commercial electronic parts manufacturers, due to increased availability, functionality and cost advantages.
- COTS used in development of Mars Science Laboratory (MSL) vehicle "Curiosity".

Commercial Of The Shelf (COTS) Advantages

- Advanced functionality and versatility of available COTS parts.
- High availability of COTS parts. High volume production as compared to low volume of military specific production.
- Allows military to incorporate new technology into military systems more quickly than in house developmental programs.
- Reduce the cost of finished assemblies.
- Modern COTS parts have been shown to be reliable under military testing conditions.
- Availability of ruggedized COTS parts to replace hermetic packages.
- Reduce operations and support costs (almost 3/4th the life cycle cost) for military systems.
- The adherence of electronics industry to published testing and qualification standards. Current federal policy is to work within commercial standards.

System Life Cycles are Increasing



Reference: R. Stogdill, "Dealing with Obsolete Parts," *IEEE Design& Test of Computers*, pp. 17-25, April-June 1999

Challenges for Avionics

- Highly diverse mission profiles.
- Harsh operating environments.
- Operation beyond temperature ratings
- Obsolescence
- Counterfeits
- Significant numbers field failures turn out to be NTF/Intermittent failures
- High availability requirements.
- Probability of failures induced during scheduled maintenance.
- Predicting the failure of a critical component in critical equipment before a mission.
- Common mode failures for redundant systems
- Single Event Upsets
- Imperfect screening and qualification standards

COTS Parts Uprating For Aerospace\Military Applications

- With transition to COTS and in general sufficient number of wide temperature range parts are not available.
- Uprating is the process to assess the ability of a part to meet the functionality and performance requirements of the applications in which the part is used outside the manufacturers' specification range.
- Assembly level testing is necessary to complete the process of uprating to
  - ensure part functionality in the system-level thermal and electrical environment
  - assess assembly level interactions
- Costly but effective.
- There is no guarantee that all COTS parts can be upgraded to meet aerospace needs.

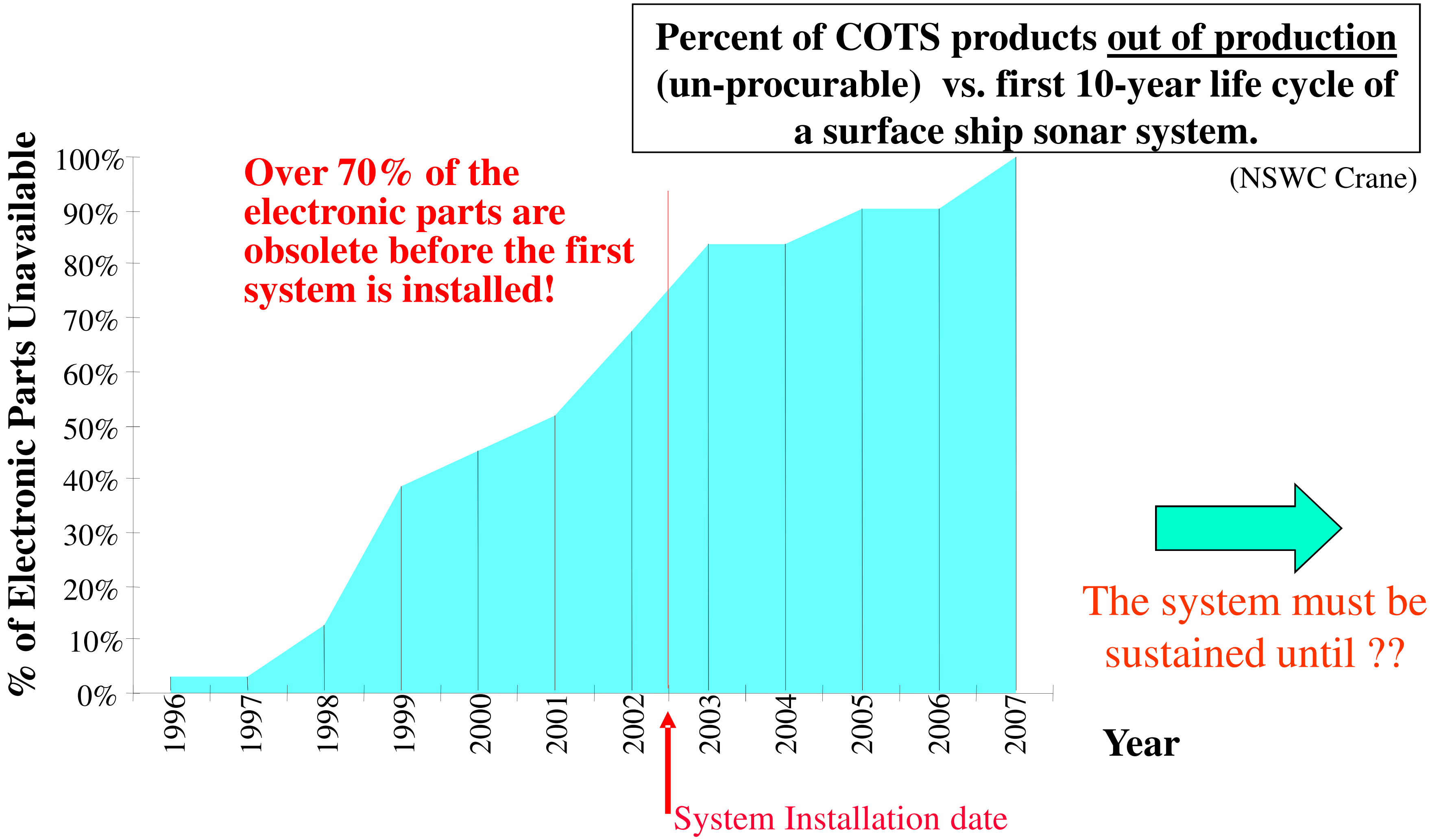
Book: **Rating and Uprating of Electronic Products,** Diganta Das, Michael Pecht, and Neeraj Pendse , *CALCE EPSC Press*, University of Maryland, College Park, MD, 2004

Changes in COTS - Environmental Regulations

- The European Union has passed environmental protection laws, including the waste electrical and electronic equipment (WEEE) and restriction of hazardous substances (ROHS) regulations.
- Other nations, including Japan, China, India and South Korea and certain states in the USA also have laws that restrict the use of environmentally hazardous substances in electronic products.
- The electronics industry has migrated to lead-free electronics (pure tin or high tin lead-free alloy finishes) as a replacement to lead-alloyed finishes.
- Though the WEEE and ROHS regulations have exemptions for military and aerospace products, the reliance on COTS components has forced the OEMs to purchase lead-free electronic parts.
- There are reliability issues related to the use of lead free parts (tin whiskers), issues of configuration control, repair, rework, recertification and obsolescence.
- Industry associations like INEMI (International Electronics Manufacturing Initiative) have conducted many studies to understand the reliability of lead free electronics.

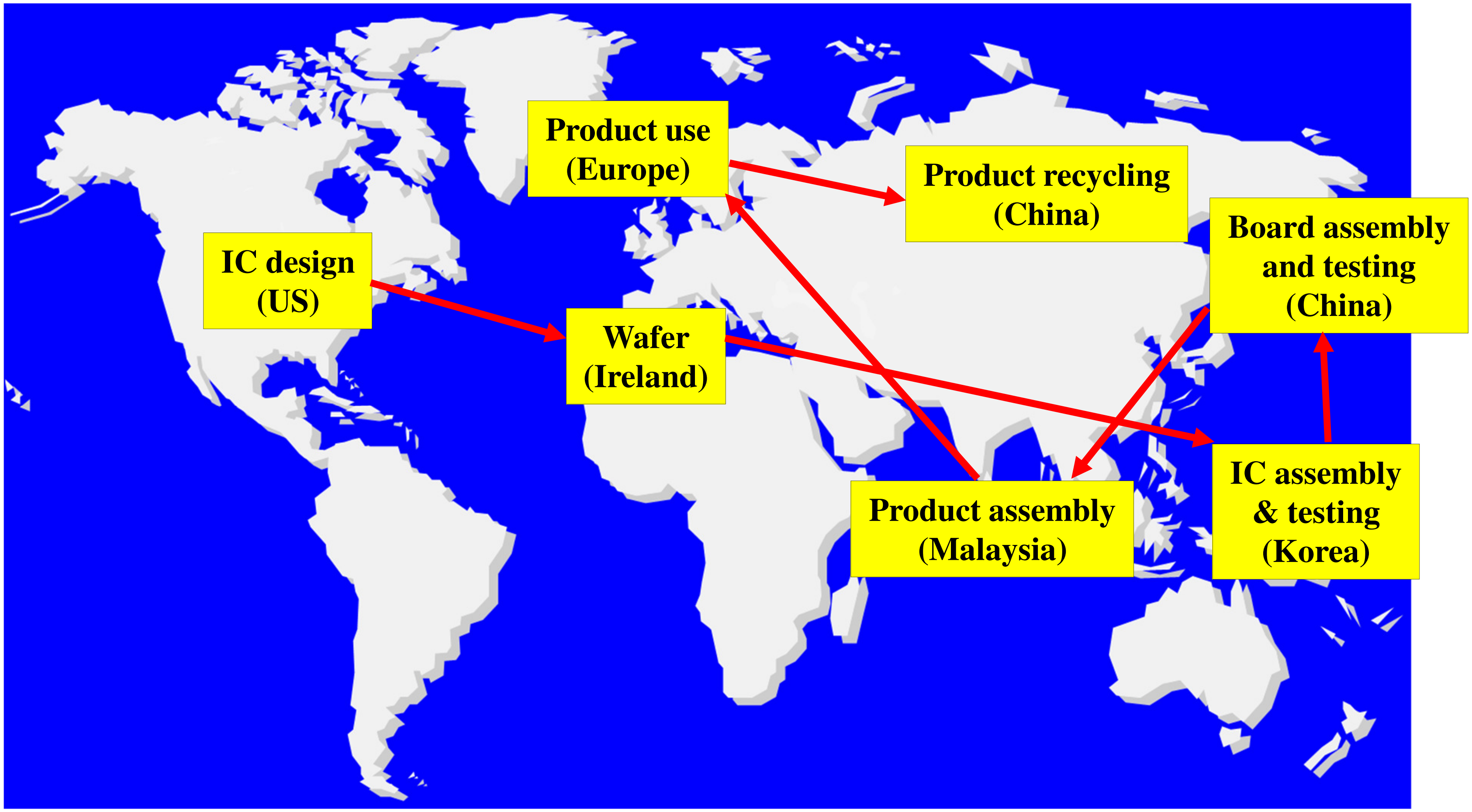
Book: **Lead-free Electronics,** Edited by Sanka Ganesan and Michael Pecht , Wiley-Interscience, Hoboken, NJ 2006

Obsolescence: A Common Situation



Book: **Strategies to the Prediction, Mitigation, and Management of Product Obsolescence,** Bjoern Bartels, Ulrich Ermel, Peter Sandborn, and Michael Pecht, Wiley, New York, NY, 2012

Global Nature of Electronic Part Supply Chain



Every participant in the supply chain can be a possible source of unauthorized parts and pass it on.

Conflict Material

- Conflict materials including gold, tin, tungsten and tantalum are used in manufacturing electronic parts.
- The *Dodd-Frank Wall Street Reform and Consumer Protection Act* signed into law on July 21, 2010 has become known as the Conflict Minerals Law that requires U.S. and foreign companies to report the source and use of conflict minerals in their products.
- The IPC (association connecting electronics industries) conduced a in-depth study of the impact of the legislation and estimates that the initial cost of complying with the statutory requirement is approximately $3 billion to $4 billion.
- Penalties for violating the new rule are unclear.
- How will these affect the supply chain for electronics industry?

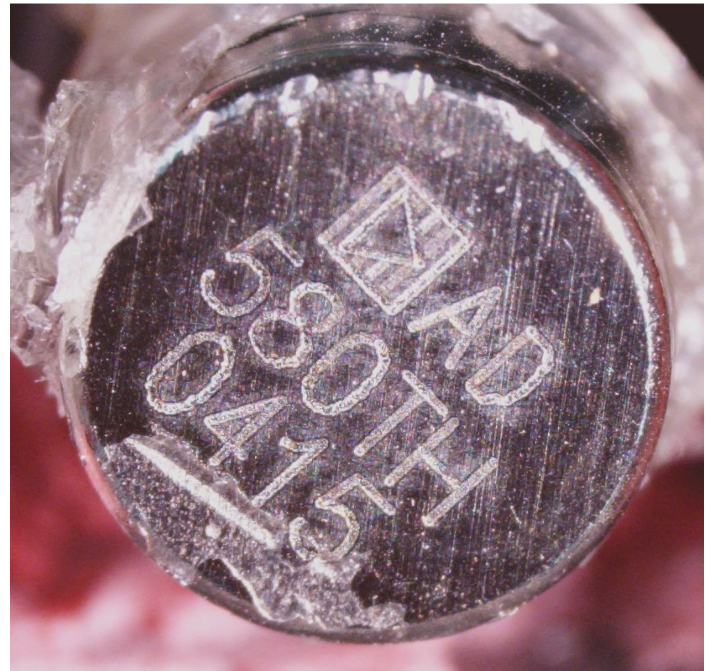
Counterfeit Parts

- The Senate Armed Services Committee discovered counterfeit electronic parts from China in the Air Force's C-130J and C-27J cargo plane, in assemblies used in the Navy's SH-60B helicopter, and in the Navy's P-8A surveillance plane.
- An amendment to the National Defense Authorization Act for Fiscal Year 2012 to promote the adoption of aggressive counterfeit avoidance practices by DOD and the defense industry.
- Reasons for counterfeits: Obsolescence, supply chain complexity, lack of a priori detection.

Screening for Counterfeit Electronic Parts, Bhanu Sood, Diganta Das and Michael Pecht, Journal of Materials Science: Materials in Electronics Vol. 22, No. 10, pp. 1511-1522

This Part Made it to a Space Mission System

Known Good Part



Suspect part. Note the Un-evenness of the letter "D" Marking errors are another red flag for counterfeit parts

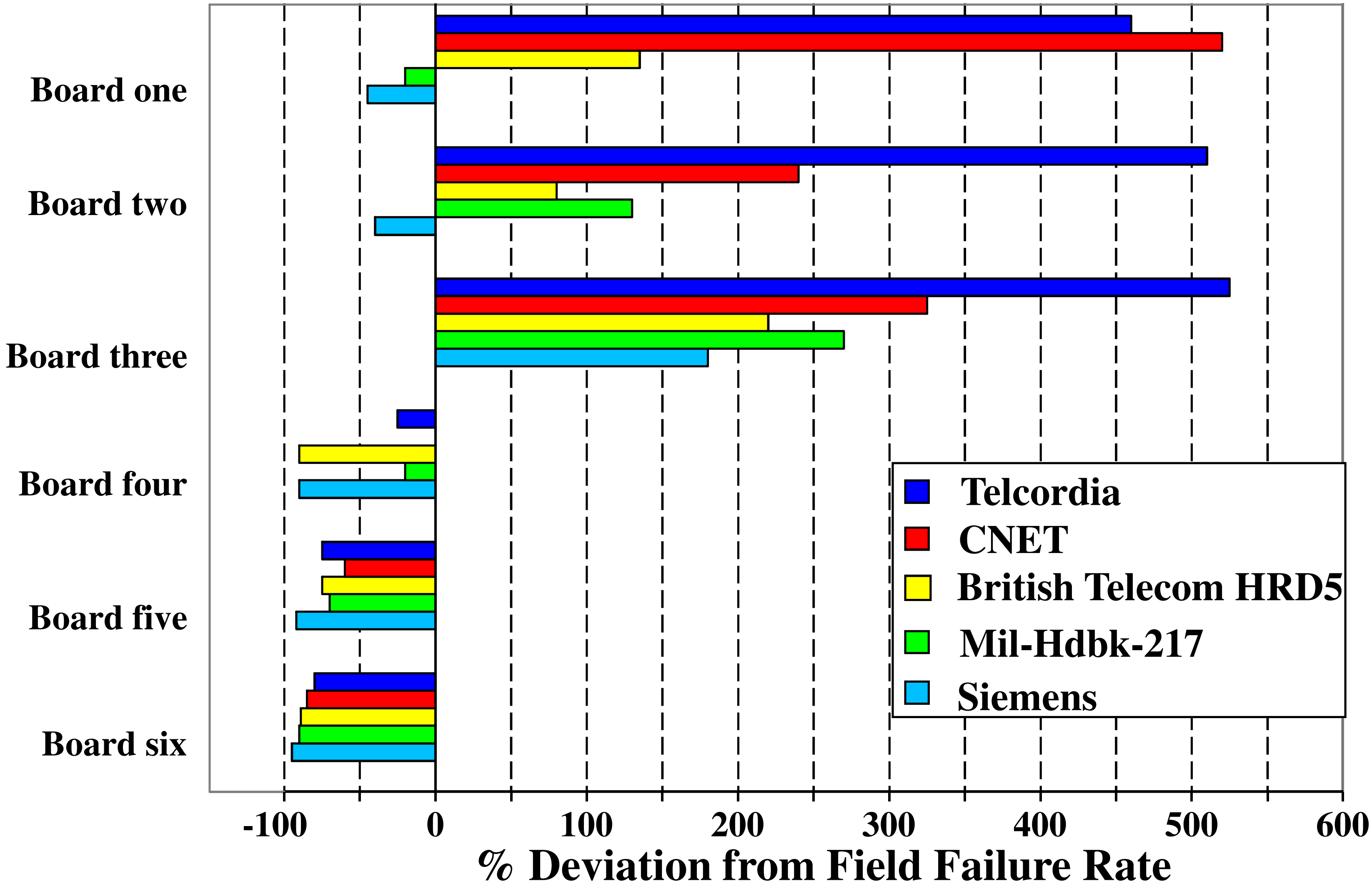
The package top is heavily scored, probably due to the supplier sanding off the original markings so they could Be over-written with part number requested by the customer.

There was an active GIDEP alert on the part number but neither the supplier nor the purchaser searched even that basic database

No Fault Found/ Intermittent Failure

- An intermittent failure is the loss of some function in a product for a limited period of time and subsequent recovery of the function.
- No-Fault-Found (NFF): Failure (fault) occurred or was reported to have occurred during product's use. The product was tested to confirm the failure, but the testing showed "no faults" in the product.
- Roughly 40 percent to 60 percent of all pilot-reported aircraft system malfunctions that occur in the air go undetected during follow-on ground testing.
- The Impact:
  - Potential safety hazards
  - Decreased equipment availability
  - Long diagnostic time and lost labor time
  - Complicated maintenance decisions
  - Customer apprehension, inconvenience and loss of customer confidence
  - Loss of company reputation
  - Increased warranty costs
- Solution: Health monitoring

Traditional Reliability Prediction Methodologies



Reference: Jones, J. and Hayes, J., "**A Comparison of Electronic Reliability Prediction Models**," *IEEE Transactions on Reliability*, Vol. 48, No. 2, pp. 127-134, 1999.

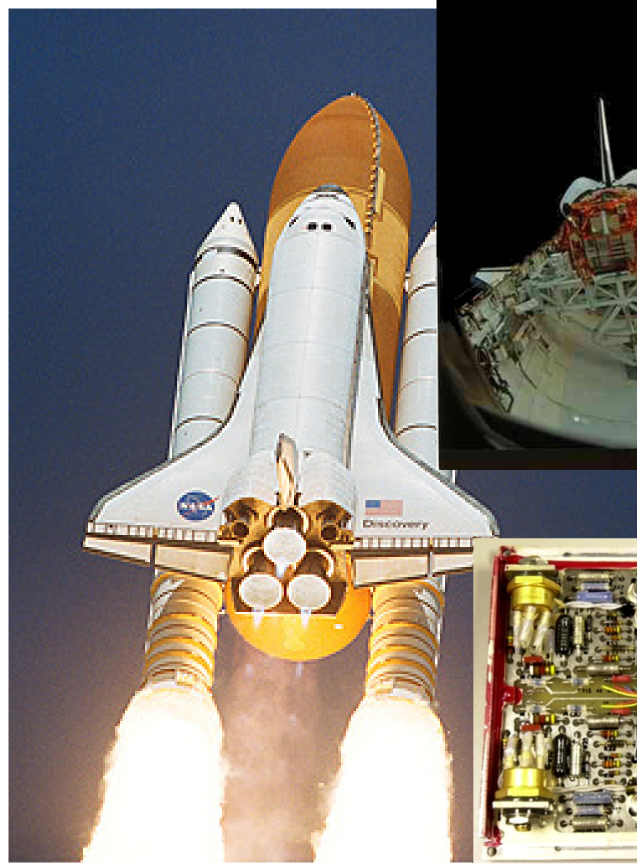
Physics of Failure Based Reliability

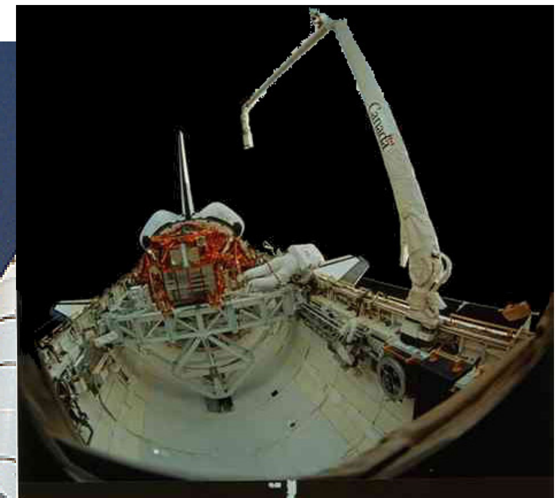
- In 1985, the U.S. Army asked CALCE at the University of Maryland to update a handbook for predicting the failure rate of electronic components.
- After reviewing the document, however, CALCE researchers concluded that MIL-Hdbk-217-and the testing procedures behind it were basically flawed.
- The major shortcoming of MIL-Hdbk-217 was its inability to address the fundamental root-cause of why and how electronic components and assemblies would fail over time.
- Researchers at Maryland offered an alternative, a new process called "**Physics of failure (PoF) analysis**".
- PoF is an approach that utilizes knowledge of a product's life-cycle loading and failure mechanisms to perform reliability modeling, design, and assessment.

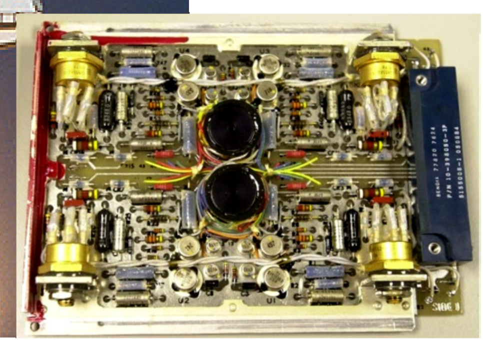
Remaining Life Assessment for NASA

CALCE utilized physics-of-failure techniques to show that the electronics on NASA space shuttle robot arm and on NASA booster rockets can survive additional mission beyond the designed –for life period. These results were used to certify future missions.

- MD Robotics and NASA continue the use of the remote manipulator system (robot arm) of the space shuttle fleet based on remaining life assessment performed by CALCE.
- BD Systems (part of SAIC) and NASA identified potential sources of mission failure based on assessment of shuttle rocket booster assembly electronics performed by CALCE.

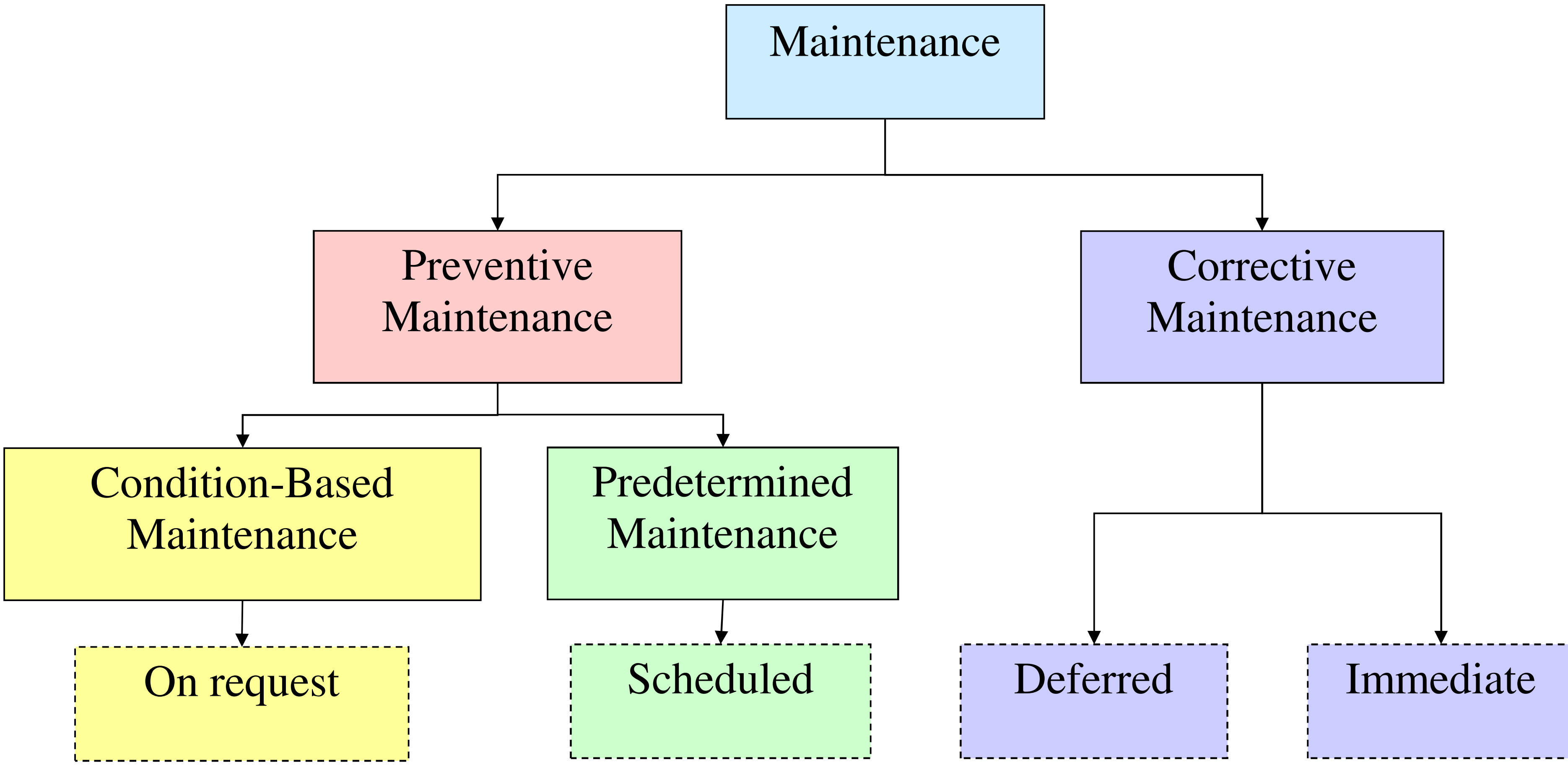






Condition Based Maintenance (CBM)

The objective of CBM is to assess a product's health during operation and determine if and when maintenance is needed.



A New Paradigm: Prognostics and Health Management

- Prognostics and health management (PHM) is an enabling discipline consisting of technologies and methods to assess the reliability of a product in its actual life cycle conditions to determine the advent of failure and mitigate system risk.
- Prognostics and health management has emerged as the new paradigm for the reliability, maintenance, and logistics community.
- The US DoD 5000.02 policy document on defense acquisition states that "program managers shall optimize operational readiness via diagnostics, prognostics and health management techniques in embedded and off-equipment applications."
- Three approaches:
  - Physics of failure
  - Data driven
  - Fusion

Book: **Prognostics and Health Management of Electronics**, Michael Pecht, Wiley-Interscience, Hoboken, NJ, August 2008

Why Prognostics?

Corrective	Predetermined	CBM
Unanticipated Failure	Regular Maintenance	Health Monitoring

Corrective – Unanticipated Failure

- Hazardous
- Costly
- Unscheduled maintenance

Predetermined – Regular Maintenance

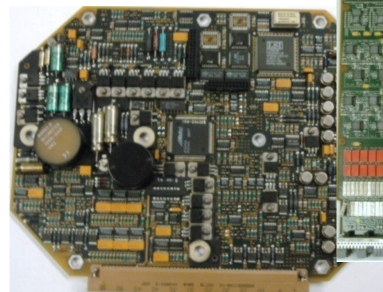
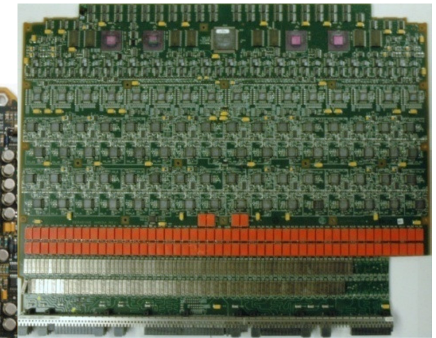
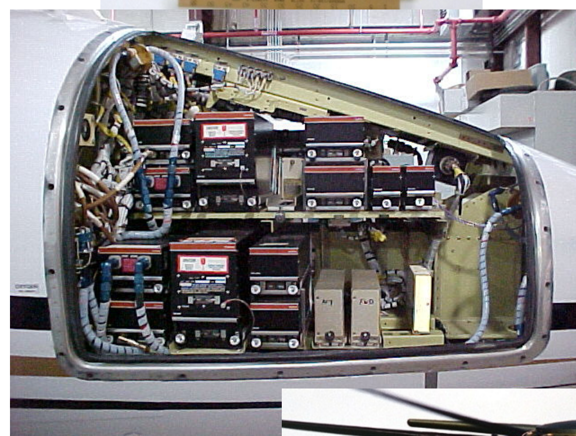
- Must inspect, repair or replace after fixed time or operational interval
- Can be costly
- Can induce failures
- Increased down-time

CBM – Health Monitoring

- Maintenance is forecasted
- Continuous monitoring of health can decrease down-time
- Product sustainment, and re-use options can be determined
- Increased safety

Applicable PHM Levels for Avionics

- LRU:
  - Switch panels,
  - Circuit boards,
  - Motherboard etc.,
- System
  - Flight management, engine control
  - Ground proximity warning systems
  - Radar etc.,
- Systems of systems
  - Aircraft communication, navigation and identification systems (C4ISR)
  - Integrated Modular Avionics etc.,

Integrated Vehicle Health Management (IVHM)

- Key areas:
  - diagnostics (identifying the root cause)
  - prognostics (predicting system health)
  - condition-based maintenance
  - adaptive control to complete a mission
- Highly integrated systems
- Advanced sensor systems
- Advanced data processing and pattern recognition algorithms
- Health prediction algorithms
- Databases
  - maintenance requests
  - root cause failures
- Decision support / human in the loop strategies
- Logistics

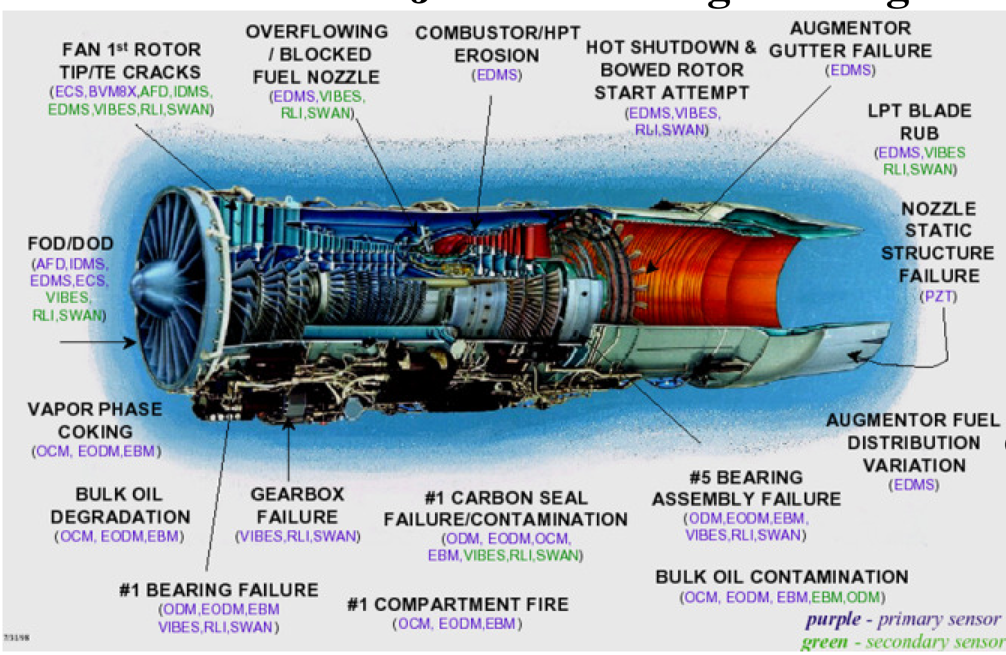
Examples of Prognostics Implementation

Source: Andy Hess, JSF Program

A-7E Crusader- Engine Monitoring System (EMS)

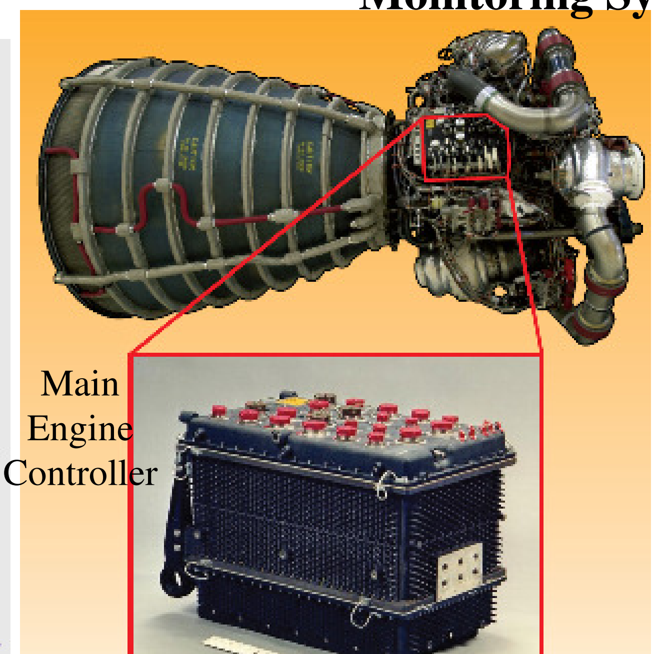
- Monitored all aspects of engine – including ignition and generators/starter
- Reduced accident rate due to engine failure by 90%
- Reduced maintenance man-hour/flight hour rate by 66%
- Overall accident rate reduced by 66%
- Useful tips for Maintenance

Instrumented Joint Strike Fighter Engine



Source: Andy Hess, JSF Program

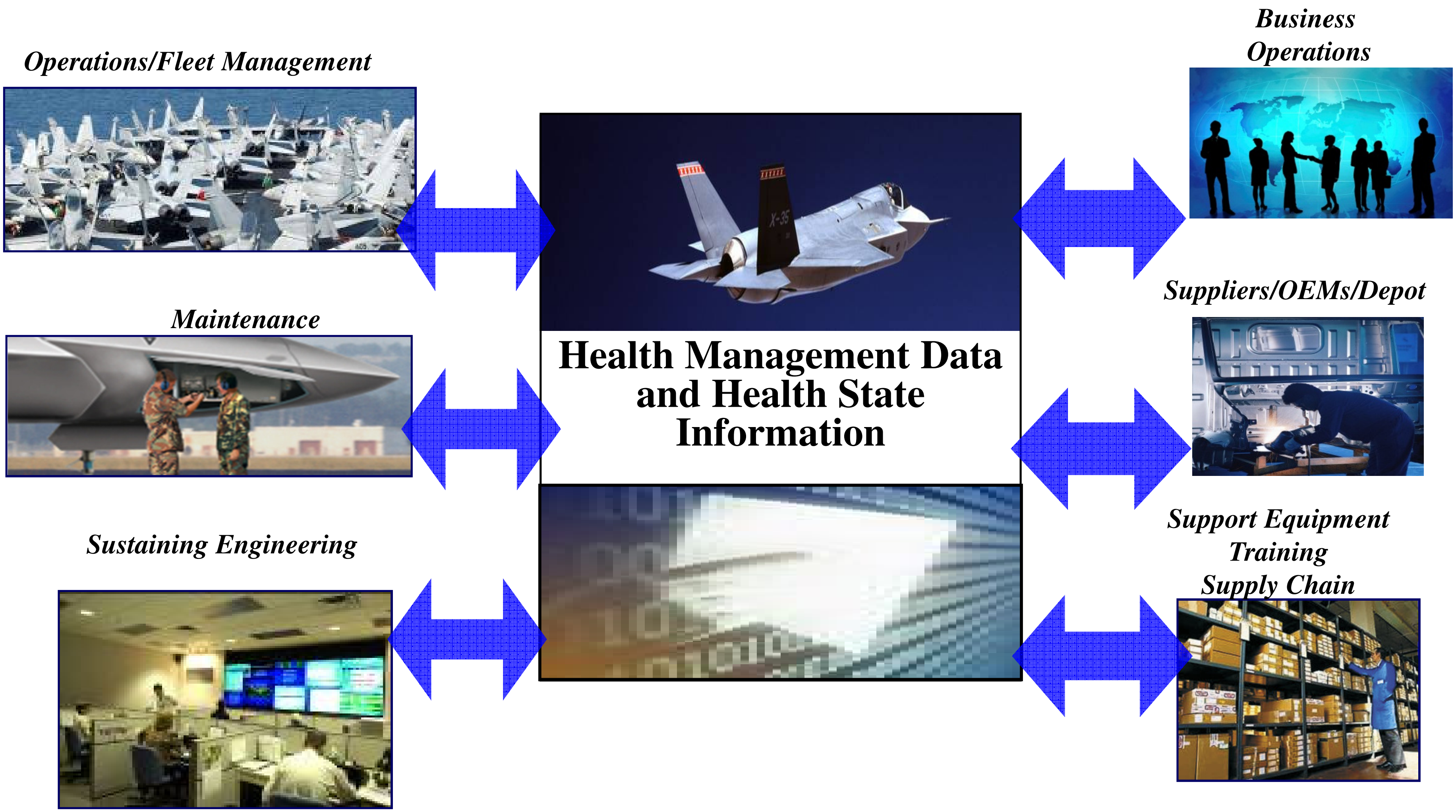
NASA's Advanced Health Monitoring System



Source: NASA

In 2007 NASA's advanced health monitoring software was integrated with the space shuttle main engine controller

Cost Centers That Benefit From PHM



Courtesy Tom Dabney, JSF Program

Potential Benefits of Implementing PHM

- Provide advanced warning of failures
- Detect intermittent faults.
- Enable condition based maintenance
- Reduce the life-cycle cost
- Reduce redundancy
- Improve availability
- Improve product qualification and reduce the qualification time
- Improve future design
- Provide guidance for life extensions
- Facilitate product re-configuration and self-healing

Thank You